Junior Course

in

Mechanical Drawing.

THORNE.

JUNIOR COURSE

IN

Mechanical Drawing,

BY

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The want of harmony between the modern practice of draughting in our best Engineering Establishments and the theories and methods given in all text-books on the subject, has led me to endeavor to present the subject of Mechanical Drawing in such a manner that the student's train of thought, method of manipulation, and knowledge of conventionalities will correspond with what experience has approved and adopted. For this purpose I have arranged three progressive courses of instruction:—A JUNIOR COURSE, treating of Lines, Plane Surfaces, and single Solids containing only plane surfaces:—AN INTERMEDIATE COURSE, treating of Solids with Curved Surfaces, the Intersection of Solids and the Development of their Surfaces:—and a SENIOR COURSE, treating of the application of these principles to the making of WORKING DRAWINGS, and of the technicalities, style, and conventionalities of practical draughting.

In the following pages, comprising the JUNIOR COURSE, those plane problems only which are actually useful, are considered, and the endeavor has been to suggest methods best adapted for ease, rapidity, accuracy, and clearness.

WM. H. THORNE.

GOWEN AVE., MOUNT AIRY,
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OUTFIT AND PREPARATION.

In pursuing this Course of Mechanical Drawing, the student should be provided with the following outfit:

Drawing Board, at least $21\frac{1}{2}$ in. by $16\frac{1}{2}$ in. Drawing Paper in sheets 21 in. by 16 in. Four Thumb Tacks for fastening paper to board. T-square with blade at least 21 in. long. One 45° Triangle, 6 in. One 30° and 60° Triangle, $7\frac{1}{2}$ in. Irregular Curve. Extra hard Pencil. File for sharpening leads. Scales of full, half, and quarter sizes, graduated to $\frac{1}{32}$ in. the *entire length.* One $3\frac{1}{2}$-in. and one $5\frac{1}{2}$-in. Compasses, with pen, pencil, and needle-points. Siberian Leads, HHHHHH, for use in Compasses. One Small Spring Bow or Spacing Dividers. One medium Ruling Pen, Writing Pen, Rubber. One bottle each of Liquid India Ink, Red Ink and Blue Ink, if for use in a class, although fine India Ink, Carmine, and Prussian Blue, to be mixed as required, are preferable but inconvenient for school purposes.

The Pencil should be sharpened with a pen-knife to a point $1\frac{1}{4}$ in. long, for $\frac{3}{8}$ in. of which the lead should be exposed. The lead is then sharpened to a flat point about $\frac{1}{32}$ in. wide for strength and durability, by rubbing it on the file. The lead in the Compasses are sharpened in the same manner. The file should be convenient for constant use in keeping the pencils in good working condition.

To prepare the drawing paper for the exercises, find by measurement the centre of the sheet vertically in the following manner: Place the Scale flat on the paper with its zero at the lower edge of the latter, and make a short, fine mark with the pencil opposite the 12-in. graduation of the scale, then shift the zero to this mark, see what graduation comes opposite the upper edge of the paper, add this dimension to the 12 in., divide the sum by two, and, after bringing the zero back to the lower edge of the paper, make a mark opposite the dimension thus found, which will be the centre of the sheet vertically.

In laying off dimensions, always do it with the Scale and Pencil. Never set the Divider points to the graduations on the Scale and prick the paper with them, as the habit is ruinous to the scale besides being an uncertain and clumsy method.

Through the central point thus found, draw a horizontal line by holding the head of the T-square against the *left-hand* edge of the Board and moving the pencil from *left to right* in contact with the upper edge of the blade.

Find the centre of the sheet horizontally in a similar manner, and through this centre draw a vertical line, by holding the T-square as before and, against its top edge, sliding the short square side of the 30° Triangle, until the long square side coincides with the desired point and using the latter side to guide the pencil, always keeping this side to the left and moving the pencil away from the person. The T-square and Triangle

are shifted up and down to make any length of vertical line required, *but the edge of the T-square itself should never be used to guide the pencil for vertical lines if it is possible to avoid it.*

These precautions limit the requirements for accuracy of work to a Board with its left-hand edge *straight*, a T-square with the *inner* edge of its *head* and the *upper* edge of its *blade* straight, a Triangle with two of its edges *straight* and *square* with each other and the other edge making angles of exactly 30° and 60° with the other sides, and a Triangle with two of its edges *straight* and *square* and the other edge at exactly 45°.

From the central horizontal line, lay off $7\frac{1}{2}$ in. above and below, and from the central vertical line, lay off 10 in. to the right and left, which will give the margin lines 15 by 20 in. and four spaces, each $7\frac{1}{2}$ by 10 in. These spaces, or subdivisions of them are the standard to be used in all the studies in this Course.

PLATE I.

FIG. 1 is an exercise in *horizontal* and *vertical parallel lines*, the horizontal being drawn by using the T-square and the vertical by using the Triangle sliding on the T-square, all the lines to be $\frac{1}{4}$ in. apart. The different kinds are designated: *a*, *fine lines;* *b*, *shade lines;* *c*, *dotted lines;* *d*, the *long and short dot;* *e*, the *long dot.*

Fig. 2 shows *inclined parallel lines,* produced by sliding one of the square edges of the Triangle along the top edge of the T-square, the inclined edge of the Triangle being used to guide the pencil, the T-square being in the position required to bring the edge of the Triangle to the desired inclination. Lines to be drawn $\frac{1}{4}$ in. apart and the kind to be varied at discretion.

To *ink* these and all other straight lines, use the Ruling Pen, filling it with ink by means of a writing pen, thus avoiding the necessity of wiping the outside. When, however, the Ruling Pen is filled by dipping it in the ink, the outside must be wiped off before using. It must also always be wiped out between the blades before laying it down and frequently during use. For this purpose, a *rag* should be kept convenient at all times as a part of the operation of inking, the same as a *file* is kept as a part of that of penciling. Keeping the instruments in good working condition is important, but trying to save ink or pencil is trifling.

The margin and division lines of the sheet are to be *Black.* All lines in Figs. 1 and 2 are to be black, except the dimension lines and the triangles in Fig. 2, which are to be *Red.* All Red lines are to be fine.

In general, *Red ink is used for all lines which are merely explanatory or imaginary.*

Dimensions are to be in *Black ink,* feet being expressed by *ft.,* inches by ″, and degrees by °.

The arrow-heads or pointers at the extremities of dimension lines must be *small* and *black*, and must always touch the line to which they extend, because they are intended to indicate definite size and not merely direction.

All the figures on the plates are drawn one-fourth size, or to a scale of 3 in. to the foot, but should be drawn full size by the student. Each Plate represents a sheet of drawing-paper 21 in. by 16 in.

FIG. 3. *To erect a perpendicular to a given horizontal line at a given point on the line.*

Length of line, 4 in.; distance of point from right-hand end, $1\frac{1}{2}$ in.

Draw a horizontal line with the T-square and lay off a length of 4 in. upon it. At a distance of $1\frac{1}{2}$ in. from the right-hand mark, make another mark for the point, through which draw a vertical line, holding the Triangle against the T-square so that the pencil, guided by the Triangle, will pass through the point. This will be the required line.

FIG. 4. *To drop a perpendicular to a given horizontal line from a given point outside the line.*

Draw a 4-in. horizontal line with the T-square. Assume any point above it and through this point draw a vertical line as before.

If the given line were vertical it would be drawn with the Triangle and the required line with the T-square.

FIG. 5. *To erect perpendiculars at the extremities of a horizontal line.*

Draw a horizontal line, lay off 4 in. upon it and erect a perpendicular at the left-hand point, as in Fig. 3. In erecting the perpendicular at the right-hand point, Fig. 5 shows the Triangle turned over in the opposite direction, that is, with its vertical edge to the right, contrary to the instructions already given. This is done to call attention to the importance of always using it in the proper manner, unless the location of the required line renders it inconvenient or impossible to do so. When it must be used in this manner, the pencil or pen, which is guided by it should be moved *toward* the person.

FIG. 6. *To erect a perpendicular to a given inclined line at a given point.*

This is an important operation to be thoroughly understood and practiced, because of its great simplicity and usefulness.

The method is based on the fact that if one of the square edges of a right-angled Triangle is held against any ruler, and a line is drawn along the hypothenuse and then the Triangle is revolved and its other square edge is held against the same ruler, a line drawn along the hypothenuse in this last position will be perpendicular to the one drawn in the first position, provided that the ruler has not meanwhile been moved.

Draw a line of any inclination and upon it lay off the dimensions given in the Fig. Bring the inclined edge of either Triangle to coincide with the line and hold it down firmly. Bring the edge of the other Triangle or of the T-square, whichever can be used most conveniently, in contact with one of the square edges of the first Triangle and hold it down firmly. Revolve

the first Triangle to bring its other square edge in contact and slide it until its inclined edge coincides with the given point, when a line drawn along the inclined edge through the point will be the perpendicular required.

Note the distinction between a vertical line and a line which is perpendicular to another line.

FIG. 7. *To bisect a given line or to divide it into two equal parts.*

Draw a 4-in. line, and upon it lay off any distance greater than one-half its length, say $2\frac{1}{4}$ in., from one end. Place the needle-point of the Compasses at this end and set the pencil-point to the mark thus laid off and describe an arc of a circle. Remove the needle-point to the other end of the line, and describe a similar arc, intersecting the first. A perpendicular to the line drawn through these intersections will bisect the line.

This method is used only for lines which are quite short. Long lines are bisected by means of the scale in the manner described on page 8.

FIG. 8. *To bisect a given angle.*

Draw any two lines intersecting each other to represent the given angle. Place the needle-point of the Compasses in this intersection, and with any arc intersect both lines. From these intersections describe arcs of radius greater than half the distance between them. Then a line drawn through the intersections of these arcs will *bisect* the angle, and should be perpendicular to one through the first intersections.

FIG. 9. *To bisect an arc of a circle.*

On a line lay off $2\frac{3}{4}$ in. as the diameter of a circle by making a mark at the zero of the scale, one at $1\frac{3}{8}$ in. and one at $2\frac{3}{4}$ in. Put the needle-point of the Compasses at the $1\frac{3}{8}$-in. mark on the line, and set the pencil-point so that it will cut both the other marks, or will average any inaccuracy in the measurement. Describe the circle, and on it mark two points to limit an arc. From these points describe arcs intersecting each other, and a line drawn through their intersections will bisect the arc and also its chord. It will be perpendicular to the chord, and will pass through the centre of the circle, and consequently will be a radius.

FIG. 10. *To find the centre of a circle which will pass through three given points, a, b, and c.*

Connect *a* and *b*, and *b* and *c*, by lines. Bisect these lines and the intersection of the bisecting lines will be the centre of a circle which will pass through the given points.

PLATE 2.

FIG. 11. *To draw a tangent to a circle at a given point, a.*

Draw a circle 2 in. diameter and assume any point on the circumference, as *a*. Draw a radius through this point. A perpendicular to this radius, drawn through the point *a*, will be the tangent required.

Fig. 12. *To draw a tangent to a circle from any given outside point, a, and to find the exact point of tangency.*

Draw a circle 2 in. diameter and assume any outside point, as *a*. From this point draw a line just touching the circle. Draw a perpendicular to this line to pass through the centre of the circle. The point of intersection of the perpendicular with the tangent line and circle will be the point of tangency.

Fig. 13. *To draw a tangent to a given circle at a given point, a, when the centre of the circle is lost or cannot be used.*

Draw an arc of a circle of $3\frac{1}{2}$ in. radius, assume any point on it, as *a*. With this point as centre and any radius, say $1\frac{1}{2}$ in., intersect the arc in two points equidistant from *a*, and connect these two points by a line. A parallel to this line (as in Fig. 2), drawn through *a* will be the tangent required.

Fig. 14. *To draw a circle tangent to another circle at a given point, a.*

Draw a $2\frac{1}{2}$-in. circle. Through the given point *a*, on the circumference, draw a radius and on this, produced, describe a circle $1\frac{1}{2}$ in. diameter, touching the first circle at the given point.

Fig. 15. *To draw a circle tangent to two other circles.*

Draw a circle 2 in. diameter and another $1\frac{3}{4}$ in. diameter, with its centre $2\frac{1}{4}$ in. from the centre of the first, and let it be required to

draw a $1\frac{1}{4}$-in. circle which will be tangent to both of these. From the centre of the first circle describe an arc of radius equal to the sum of the radii of the first circle and the tangent circle, or $1\frac{5}{8}$ in. Intersect this arc with another described from the centre of the second circle, of radius equal to the sum of the radii of the second circle and tangent circle, or $1\frac{1}{2}$ in. The intersection of these arcs will be the centre of the tangent circle.

FIG. 16. *Angles are measured by equal divisions, called degrees, of a circle whose centre is at the intersection of the lines forming the angle.*

The circle is divided into 360°, and the zero can be taken at either extremity of either the horizontal or vertical diameters. By means of the two triangles already provided, an angle of 15°, or any multiple thereof, can be drawn.

Draw a 3-in. circle and its horizontal and vertical diameters and mark the extremities of the former 0°, and of the latter 90°. Draw two diameters with the 45° Triangle in its two different positions. Draw four diameters with the 30° Triangle in its four different positions. Draw four other diameters with the 30° and 45° Triangles, both combined in four different positions. These diameters will divide the circle into arcs of 15° each.

FIG. 17. *In Trigonometry, angles are dealt with by means of certain lines, called the functions of the circle, a graphical illustration of which is given in this figure.*

Draw a 3-in. circle, a horizontal diameter *ka,* and a vertical radius *cg.* From the centre of the circle draw an indefinite line *ch,* making any angle, say 30°, with *ka,* then *hca* will be the *angle,* and the difference between this and 90° or *hcg,* will be the *complement* of the angle. From the point *d,* where *ch* intersects the circle, draw a horizontal line, *df,* and a vertical line, *de.* From *a* draw a vertical line *ab,* and from *g* a horizontal line *gh.* Then *ca=Radius, ab=Tangent, de=Sine, df=Co-sine, cb=Secant, ch=Co-secant,* and *gh=Co-tangent.*

FIG. 18. In this figure, the right line *ag* is a *diameter, bf* a *chord, de* a *chord, ch* a *radius,* and *cm* a *radius,* while the circular line *de* is an *arc, bf* an *arc,* and *ag* a *semicircle.* The portion of the surface included between an arc and its chord, as *de,* is a *segment,* that between two chords, as *bdef* a *zone,* that between two radii and their arc, as *chm,* a *sector,* while a sector of 90°, as *acm* is a *quadrant.*

FIG. 19. *An* EQUILATERAL TRIANGLE *is a plain figure with three equal sides.*

On a horizontal line lay off $1\frac{3}{4}$ in. for the base of the triangle. Since the sides are equal, the angles must be equal. The sum of the angles in a triangle is always equal to two right angles or 180°, one-third of which is 60°. Hence, lines drawn from the extremities of the base with the 60° Triangle will intersect to produce an *equilateral triangle.*

FIG. 20. *An Isosceles Triangle has two of its sides equal.*

Draw a horizontal base $1\frac{3}{4}$ in., from each extremity of which, as a centre, describe an arc of $2\frac{1}{4}$ in. radius. The intersection of these arcs will be the apex of the Isosceles Triangle.

FIG. 21. *A* SCALENE *Triangle has all of its sides unequal.*

Draw a horizontal base $1\frac{1}{4}$ in., from one extremity of which describe an arc $1\frac{3}{4}$ in. radius, and from the other, an arc $2\frac{1}{2}$ in. radius. Lines connecting these extremities with the intersection of the arcs will complete the Scalene Triangle.

FIG. 22. *A* RIGHT-ANGLED TRIANGLE *has one right angle* (90°).

Draw a horizontal base $1\frac{3}{4}$ in., at one extremity of which erect a perpendicular, 2 in. The line completing the triangle is the *hypothenuse.*

FIG. 23. *A* SQUARE *is a plane figure with four equal sides and four equal angles, each* 90°.

Draw a horizontal base $1\frac{3}{4}$ in., and a perpendicular side $1\frac{3}{4}$ in. Draw the other sides parallel, respectively, with this base and side to complete the square.

FIG. 24. *A* RHOMBUS *has four equal sides, but unequal angles.*

Opposite angles are equal and opposite sides parallel.

Let the length of the sides be $1\frac{1}{2}$ in. and the inclination be $\frac{1}{2}$ in. Draw a horizontal base $1\frac{1}{2}$ in. At a distance of $\frac{1}{2}$ an in. from one

end of the base, erect a perpendicular, and from this end of the base, with a radius of $1\frac{1}{2}$ in., describe an arc cutting the perpendicular. Through this intersection draw a horizontal line for the side opposite the base. Draw an inclined line from the intersection to one end of the base and from the other end draw a parallel line cutting the side opposite the base. This will complete the Rhombus.

FIG. 25. *A* RECTANGLE *has four equal angles* (90°).

Draw a rectangle $1\frac{1}{4}$ in. wide and 2 in. high.

FIG. 26. *A* RHOMBOID *has its opposite sides equal, but its angles not right angles.*

Let the sides be 2 and $1\frac{1}{4}$ in., and the inclination of the short side be $\frac{1}{4}$ in.

Draw a horizontal line and erect a 2-in. perpendicular to it. From the foot of the perpendicular describe an arc $1\frac{1}{4}$ in. radius. Draw a second horizontal line $\frac{1}{4}$ in. above the first. Draw a line from the intersection of the arc with the second horizontal line to the foot of the perpendicular, and a parallel line from the top of the perpendicular. A second perpendicular, drawn from the same intersection, will complete the Rhombus.

FIG. 27. *Given a circle, to inscribe or circumscribe a* PENTAGON *or plane figure with five equal sides.* Draw a $2\frac{1}{2}$-in. circle, and with the spacing dividers, set by guess to a distance approximately one and one-sixth times the

radius, step around the circle, being careful to keep exactly on the circumference and to *not* prick the paper. Judge by the result whether to increase or diminish this distance. Continue the trial until the fifth step coincides with the starting-point. Then step around finally, making prick marks which can be seen. Lines connecting these prick marks will form an *inscribed Pentagon* and tangents to the circle at these points (as in Fig. 11) will form a *circumscribed Pentagon.*

FIG. 28. *To inscribe and circumscribe a* HEXAGON *or plane figure with six equal sides.* Draw three diameters at angles of 60° with each other. Lines connecting the extremities of these diameters will form the *inscribed Hexagon.* Draw six tangents to the circle with the T-square and 30° Triangle to form the *circumscribed Hexagon.*

The diameter of the circle is commonly called the *diameter across corners* or long diameter of the inscribed hexagon and the *diameter across flats* or short diameter of the circumscribed hexagon.

FIG. 29. *To inscribe or circumscribe a* HEPTAGON *or plane figure with seven equal sides.*

Divide the circle, as in Fig. 27, by stepping seven sides.

FIG. 30. *To inscribe or circumscribe an* OCTAGON *or plane figure with eight equal sides.*

Proceed as in Fig. 28, but using the 45° Triangle.

PLATE 3.

FIG. 31. *Given the length* ab, *or major axis, and width* de, *or minor axis, to construct an* ELLIPSE.

An Ellipse is a curve generated by a point moving in a plane so that the sum of the distances of this moving point from two fixed points shall be constantly equal.

To understand this, drive two tacks in a board, to each of which fasten one end of a string of any length greater than the distance between the tacks, and press a piece of chalk or pencil against the string to keep it taut. The pencil is the *generating point,* and the length of the string is the sum of its distances from the two fixed points [the tacks] called the *foci.* Travel the pencil around on the board, guided by the string, and it will describe an Ellipse. A moment's thought will show that the length of the string is equal to the length of the Ellipse, or the major axis, therefore if, when the major and minor axes are given, we describe arcs from the extremities of the minor axis of radius equal to half of the major axis, the intersections of these arcs with the major axis will give us the foci. If, now, we describe arcs from each focus with any portion of the major axis as radius and intersect these by arcs from each opposite focus with the remaining portion of the major axis as radius, the intersection of these arcs will be points of the Ellipse.

On this principle, describe an Ellipse 4 in. long and $2\frac{1}{2}$ in. wide.

Intersect the major axis by arcs of 2 in. radius, struck from *d* and *e*, to obtain the foci *ff*. With any portion of *ab* as radius, as *ag*, describe arcs from *f* and *f* and, with the remaining portion, *bg*, as radius, intersect these arcs. Proceed with other portions of *ab* as radius until enough intersections are obtained. Set the *Irregular Curve* to coincide with as many of these as possible, and draw a curved line through them. As the Ellipse is symmetrical about the two axes, make slight pencil marks on the Irregular Curve to include the portion of its edge just used and transfer these marks to opposite sides in order to identify the portion required for making three other similar parts of the Ellipse. Then shift the Irregular Curve to correspond with other intersections, and so on. A small portion of the ends of the Ellipse can be drawn with the compasses to insure symmetry.

To facilitate the use of the Irregular Curve it is a good plan to make marks about $\frac{1}{8}$ in. apart along the edges on both sides, exactly opposite each other, and number each fourth mark consecutively, but the same on both sides. This enables the same portion of the curve to be readily used in different places, or to be reversed for symmetrical work.

FIG. 32. *To describe an* OVAL *or approximate Ellipse, by means of circular arcs, when the length and width are given.*

Let the length *ab*, be 4 in., and the width *de*, be $2\frac{1}{2}$ in.

Lay off half the width,=*cd*, from one end of the length,=*bf*. The remaining portion of the length will be the radius, *gh*, for the top and bottom

of the oval. From f toward b lay off one-half of $fc = fk$. Then kb will be the radius of the ends of the oval.

The majority of the Ellipses, which occur in draughting, can be approximated by this method with sufficient accuracy for practical purposes.

FIG. 33. *A* PARABOLA *is a curve generated by a point moving in a plane so that its distance from a given point shall be constantly equal to its distance from a given line.*

The given point, f, is the *focus*, the given line, cd, the *directrix*, the line through the focus perpendicular to the directrix, vf, is the *axis*, and the intersection of the curve with the axis, v, is the *apex*.

To draw a Parabola with the focus, f, at a distance of 1 in. from the directrix, cd. Locate the vertex, v, at one-half the distance between the focus and directrix. Draw a series of lines parallel to the directrix. With the focus as centre, cut each of these lines with an arc of radius equal to the distance of the line from the directrix and the intersections will be points of the curve. Draw the curve as in Fig. 31.

FIG. 34. *To construct a* PARABOLA *when the height, or abscissa, vb, and the width, or twice the ordinate ab, are given.*

Draw a rectangle of the given height, $2\frac{1}{4}$ in., and width, $3\frac{1}{4}$ in. Divide the base into any number of *equal* parts and erect perpendiculars at these points. Divide the side of the rectangle into the *same* number of *equal*

parts and draw lines from these points to the vertex. Where each of these lines intersects the corresponding perpendicular will be a point of the curve.

FIG. 35. There are certain ROLLED CURVES, which are useful in mechanics, and an understanding of which is important.

A CYCLOID *is a curve generated by a point on the circumference of a circle rolling upon a straight line without slipping.*

Draw a horizontal base line and above it a circle 2 in. diameter and below it one 4 in. diameter, the centres being on the same perpendicular. Let the upper circle be rolled to the left and the lower to the right. Draw a horizontal line through the centre of each circle to indicate the paths of these centres. With the spacing dividers, step equal divisions, say $\frac{3}{16}$ in., along the base line, starting at the vertical centre line. At each of these divisions draw perpendiculars to intersect the horizontal centre lines. From each of these intersections describe portions of the original circles, which will represent their positions after having rolled to each successive division. With the spacing dividers unaltered and starting from the divisions on the base lines, step back on each corresponding circle the number of divisions it has moved from the original position, or, in other words, measure on the circumference of the rolling circle in its successive positions the length of the portion of the base line on which it has rolled. By using small divisions the error arising from the difference between arc and chord will be inappreciable.

FIG. 36. *An* EPICYCLOID *is a curve generated by a point on the circumference of a circle rolling on the* OUTSIDE *of another circle without slipping, and a* HYPOCYCLOID *is that generated by rolling on the* INSIDE.

On a vertical centre-line draw a portion of a *base-circle* 8 in. diameter, and, tangent to it on the same centre-line, draw an outside and an inside rolling or *generating-circle* 2 in. diameter. From the centre of the base-circle describe arcs passing through the centres of the rolling-circles to show the paths of these centres. From the point of tangency step equal divisions, say $\frac{3}{16}$ in., on the base-circle and from the centre of the latter draw radial lines through these divisions intersecting the paths of centres. From each of these intersections describe portions of the rolling-circle and on them step off the original divisions in the same manner as in Fig. 35.

FIG. 37. This is the same as Fig. 36, excepting that the base-circle is 4 in. diameter, the rolling-circle remaining 2 in. It illustrates a curious and important fact, namely, that *when the diameter of the Rolling-Circle is one-half that of the Base-Circle, the Hypocycloid becomes a straight line, a radius.*

FIG. 38. *An* INVOLUTE *is a curve generated by a point on a straight line rolling on a circle without slipping, or, more clearly, it is the curve described by the end of a taut string as it is unwound from a circle.*

Draw a circle 2 in. diameter and, starting from any desired point, step off equal divisions, $\frac{3}{16}$ in., on the circumference. Draw tangents at

each of these divisions and from the point of tangency step off on each tangent the original division as many times as the point is distant from the starting-point or, in other words, measure on each tangent the length of the arc of which it is the development.

Construct also the Involute of a circle 4 in. diameter.

PLATE 4.

Heretofore we have been treating entirely of points, lines and surfaces. We have seen that *points* have no dimensions, neither length, breadth nor thickness, that *lines* have only length and that *surfaces* have only length and breadth. We have seen that the points, lines, and surfaces, which we have considered, lie in one plane and can be fully determined and expressed by one view on the paper.

It now becomes necessary for us to express *Solids* in such manner that their form and dimensions shall be so fully determined that the solid object itself can be constructed without any further description or explanation than that given in the drawing.

This is the sole purpose of MECHANICAL DRAWING, *to give such an illustration of the required object as to enable it to be accurately and definitely built from the drawing* and the drawing alone, and not to make a picture or representation of the object as it would appear in nature.

As all solid objects have length, breadth, and thickness, and as only two of

these dimensions can be represented in exact form and size on one plane or view, *it is necessary to use more than one view for the complete determination of all solids.* As the paper, on which the drawing is made, lies in one plane only, it is necessary to devise a clear, simple, logical, and uniform method of representing the other planes or of drawing the various views, so that the different parts of the object will be shown in form and size and in their proper relation to each other, in order that the workman can accurately construct it without any verbal directions.

FIG. 39. *Let it be required to make a Mechanical Drawing of a Rectangular Prism $2\frac{1}{2}$ in. high, 2 in. wide, and 1 in. thick.*

We know that this has six sides, the opposite ones being equal rectangles; hence, to show the shape of the different surfaces of the prism it is necessary to draw three rectangles. How shall we arrange three rectangles to make clear what they represent and to prevent any misunderstanding of the meaning of the drawing? The best method for this and the one used by the most progressive American and English draughtsmen is based upon the following theory.

The object is supposed to be surrounded by planes at a short distance from it, the planes being perpendicular to each other. From each point of the object, perpendicular to each of these planes, lines are supposed to be projected, and the points of intersection of these perpendicular lines with these planes form the *Projections* of the object. One of these planes is supposed

to be the plane of the paper and all the other planes to be revolved about their intersections with this plane until they coincide with it, thus bringing them all into the plane of the paper. The lines of intersection of the planes with each other are called the *Axes of Projection.* They are the axes or hinges, as it were, about which the planes are supposed to be swung.

To understand this clearly draw upon a square piece of card-board a horizontal line, *hth′*, and a vertical line, *vth″*, to represent these axes of projection. Cut out the corner, *h′th″*, and fold the card on the lines *ht* and *vt* into positions at right angles with the original. By standing this on its lower edges upon a table it will be seen that *vth* and *vth′* are vertical planes perpendicular to each other, and that *hth″* is a horizontal plane perpendicular to both the others, that the axis *vt* is vertical, the axis *ht* horizontal, and that *h′t* and *h″t* coincide and are horizontal. The object to be drawn, a rectangular prism in this instance, is supposed to be upon the table surrounded by these planes. It will, therefore, be behind *vth*, to the left of *vth′*, and below *hth″*, and the projections drawn on *vth* will represent a front view, called the FRONT ELEVATION, those on *vth′* a right-hand side view, called the SIDE ELEVATION, and those on *hth″* a top view, called the PLAN. If the card is then flattened out and laid upon the drawing-board it will be seen how two of the planes are supposed to be revolved upon the axes to bring them into the one plane of the drawing-paper. It will also be noted that the top view comes above the front view, the right-hand side view

to the right, and the left-hand side view (if one were necessary) would come to the left, thus making the clearest, most logical, and most convenient relative arrangement.

To proceed with the drawing of the rectangular prism, draw a rectangle $2\frac{1}{2}$ in. high and 2 in. wide. This will be the FRONT ELEVATION. At a short distance above this, say $\frac{3}{4}$ in., draw the horizontal line *ht*, which will represent the edge of a horizontal Plane of Projection or more properly its intersection with the vertical plane of projection, called its *trace* on that plane, and will be the horizontal axis of projection. The drawing thus far represents the projection of the prism on a vertical plane in front of it, and shows a horizontal plane above it. Now draw lines, with long-and-short dot, perpendicular to *ht* to represent the vertical *Projecting Lines* from the prism which intersect the horizontal plane of projection. Fix upon the distance which the prism is supposed to be behind the vertical plane, say $\frac{3}{4}$ in., imagine the horizontal plane revolved up into the plane of the paper (or in line with the vertical plane) and continue the projecting lines indefinitely. The projection of the prism on this horizontal plane will be a rectangle, the ends of which will be part of the projecting lines already drawn, the front of which will be a line parallel to *ht* and $\frac{3}{4}$ in. behind it, and the back of which will be another horizontal parallel line at a distance of 1 in., the thickness of the prism, from the first. This will complete the PLAN.

These *two* views are all that are really necessary for a simple object like

this prism, as the length, breadth, and thickness are fully determined by them, but it is best to make *three* views in all our studies of principles, because in actual practice very few drawings of structures having any complication can be made to give all necessary information by means of two views only.

To draw the third view or SIDE ELEVATION imagine a vertical plane $\frac{3}{4}$ in. to the right of the prism, draw its *trace* vt, and imagine it revolved into the plane of the paper. Then vt will be the vertical and th' the horizontal axis of projection, and th' will be the same as th''. To prove that th' and th'' are different views of the same line, cut the card-board model of the planes of the projection on the line vt and hinge th' to th'', when the planes will fold into the original box-shape, and will unfold to bring the plane vth' to the right of hth'' instead of to the right of vth as before; or the SIDE ELEVATION will come to the right of the PLAN instead of to the right of the FRONT ELEVATION, and will be at right angles to its former position, an arrangement of the views which often proves convenient.

Having now determined the side vertical plane vth', draw horizontal projecting lines from the Front Elevation indefinitely to the right and from the Plan to the axis th''. With t as a centre, describe arcs indicating the revolution of the side vertical plane, and drop vertical projecting lines from these arcs to intersect the horizontal ones already drawn. The lines included between these intersections will be the projection of the Prism upon a vertical plane perpendicular to the former one and will complete the Side Elevation.

A thorough understanding of these principles, which are the very foundation of correct mechanical drawing, is very important, and this Figure should not be passed until it is obtained.

The next step is to *ink* the drawing, and no mechanical drawing is complete, or anything more than a sketch, until inked.

We have already seen that in drawing a simple prism lines have been used which do not represent any part of the prism, but merely indicate imaginary planes and lines of projection, and it is evident that if all these lines were inked in the same manner, the result would be confusing and the effect inartistic. The first object being to bring the shape and size of the prism out prominently and clearly, its projections should be inked *black*. Hence the rule:—*All lines representing parts of the* OBJECT *should be black, those representing visible parts being full lines and those representing hidden parts being dotted lines.*

The clearness, beauty, and realism of the drawing are increased by making certain lines heavy after a conventional mode, which, although not scientific, has proven to be the most efficient and to require the least mental effort in selection. These heavy lines are called SHADE LINES. The scientific method, which is universally taught and never practiced after the first blush of apprenticeship, indicates by shade lines the shadows which would be produced by rays of light falling upon the actual object at angles of 45° with both the horizontal and vertical planes, the direction being from the

left front. This distributes the shade lines in the several views in the following manner:—In the Front Elevation the right-hand and lower edges; in the Plan, the right-hand and upper edges; in the right Side Elevation the right-hand and lower edges, and in the left Side Elevation, the left-hand and lower edges.

In the conventional method, *the right-hand and lower edges are made shade lines in all the views,* thus enabling the process to soon become a mere matter of habit, requiring but little thought, while the scientific method requires constant care to avoid placing them incorrectly, because of their not being in the same relative position in all the views. As all the drawings in the accompanying Plates are shade-lined by the conventional method, attention to them will probably be of more service than any further description. One rule, however, should always be borne in mind,—*Never make the line of intersection of two planes, of which both can be seen, a shade line.*

On the subject of *inking,* the following rules should be observed:

Always ink the black lines first.

Always ink all the circles and curves before the straight lines, because they are generally tangent to straight lines, and it is easier to draw a straight line correctly tangent to a curve than the reverse.

The lower right-hand quadrant of exterior, and the upper left-hand quadrant of interior curved edges should be shaded with the heavy part gradually blended into the fine part.

Always ink the fine straight lines next after the curves by setting the pen to the desired degree of fineness and making all the fine lines of the drawing without altering the pen, in order to produce the effect of uniformity.

Last of all, open the pen and *make all the shade lines of one thickness.*

All dotted lines are black and fine.

The black lines being all completed, *ink next the axes of projection, centre lines, and any important bases or lines of reference* which do not represent any part of the object but are desired as explanatory. *These lines should be* BLUE, but can be red.

Next ink the dimension lines, projecting lines, and any construction lines used in obtaining the lines of the object, the preservation of which is desirable. These lines should be RED.

The Arrow-heads or Index Points at the extremities of the dimension-lines should be black, made with the writing pen, and should always be in actual contact with the line to which they point, because they indicate definite size and not merely direction.

Always write the dimensions in line with and never inclined or perpendicular to the dimension-line.

Never make an inclined line between the numerator and denominator of a fraction, as the practice is apt to cause mistakes in reading the dimension.

For all lettering on a drawing, adopt some style of printing or conventional script, and never use your ordinary handwriting.

All Blue and all Red lines should be finer than the fine black lines, in order to avoid giving them prominence.

The lines which have been directed to be blue may be red, but in a drawing of much detail it adds to the clearness to make them blue.

FIG. 40. This is the same as Fig. 39, except that the prism has an opening through its thickness $1\frac{3}{4}$ in. high and $1\frac{1}{4}$ in. wide, leaving walls $\frac{3}{8}$ in. thick. As this opening is invisible in the Plan and Side Elevation, its projections in these views are shown by black dotted lines, which, as already explained, are used for indicating invisible lines of the object.

FIG. 41. Although a mechanical drawing of any required object is always made with the planes of projection parallel to the main features of the object, yet, in designing large structures, it frequently occurs that one integral part is at an angle with another, and it thus becomes important to understand the theory and be proficient in the practice of making projections on planes which are not parallel with these main features.

In this figure it is required to draw the same object as in the last, but with its front making an angle of 30° with the front vertical plane of projection, as shown. Draw the Plan complete at the required angle. Lay off on the front vertical plane the outside and inside heights and project these across to the side vertical plane. Draw projecting lines from all the points in

the Plan to both the vertical planes to locate the position of these points on the indefinite horizontal projecting lines already drawn. In inking this figure, be careful to dot all the lines which are hidden.

FIG. 42. Draw the same object with its front inclined at an angle of 45° with the vertical plane and in the opposite direction from that in the last figure.

As this figure completes the first plate of projections, the student, before going to the next, should draw other rectangular prisms of different dimensions and twisted on the horizontal plane to different angles, in order to become familiar with the principles.

PLATE 5.

FIG. 43. *To make a mechanical drawing of a* WEDGE $2\frac{1}{2}$ *in. high, with a base* 2 *in. long and* 1 *in. wide.*

Draw, in the Plan, the rectangle of the base and the line of intersection of the two inclined sides, which line will coincide, in this view, with the centre line of the base. Draw the projecting lines to the Front and Side Elevations. Lay off the perpendicular height of the wedge on the vertical projecting line which passes through the centre of the base in the Side Elevation and complete this view by drawing a horizontal projecting line for the base and connecting its extremities with the apex by inclined lines. Project the apex and the base across to complete the Front Elevation.

3

FIG. 44. *Draw the same* WEDGE *with its base remaining horizontal, but at an angle of 45° with the vertical planes of projection.*

An evident fact to be noted and always remembered is that *if any point, line or solid is moved or twisted on a horizontal plane, the height of its projections on the vertical planes will not be altered thereby.*

FIG. 45. *Draw a* RECTANGULAR PYRAMID *with a vertical height of* $2\frac{1}{2}$ *in. and a base 2 in. long and 1 in. wide.*

FIG. 46. *Draw a* TRIANGULAR PRISM *with sides* $2\frac{1}{2}$ *in. long and 2 in. wide, one side to be in a horizontal plane.*

On the completion of this plate, the student should make another with the Pyramid of Fig. 45 twisted on the horizontal plane to different angles and with another Pyramid of different proportions.

PLATE 6.

In order to acquire familiarity with the theory and a complete understanding of the meaning and relation of the three views in a drawing, we have heretofore drawn the axes of projection and have used them as bases to work from. They have served the purpose of lines of demarcation between the planes of projection and of constant reminders that the different views are projections of the same object on different planes perpendicular to each other. We will now discontinue the actual use of these lines, although they must not be

lost sight of in imagination, but the fact must always be borne in mind that when one view of an object is projected directly from another view, the two planes of projection are always at right angles with each other, and that there is an intersection of these two planes which would be the *Axis.*

Besides omitting the axis, we shall now abbreviate the Projecting Lines, making them merely sufficient to indicate the direction, and shall eventually omit them altogether, because it is desirable to have a drawing free of all lines which do not facilitate a comprehension of it.

FIG. 47. *Let it be required to draw a hollow Triangular Prism open at the ends, each side being $2\frac{1}{2}$ in. long, 2 in. wide, and $\frac{3}{8}$ in. thick, one of the sides being horizontal and at an angle of 30° with the front vertical plane.*

Locate in the Plan a point for the position of the centre of the horizontal side of the prism, through which point draw the horizontal line *ab.* This will be the trace on the horizontal plane of projection of a vertical plane parallel to the front vertical plane of projection. (*By the trace of a plane is meant its line of intersection with another plane.*) At an angle of 30° with *ab* and passing through the central point already located, draw the CENTRE LINE *cd,* which will represent a central vertical plane parallel with the edges of the prism. On this centre line complete the plan of the horizontal side of the prism. This will, of course, be its projection on a horizontal plane. We now want a vertical plane on which to draw the triangular end of the prism. The axis of such a plane must be parallel to the short side of the rectangle in the Plan

and the projection of this side on the plane must be a line also parallel. Hence, project this line, and on it construct the END ELEVATION of the prism. This End Elevation is the projection of the prism upon a vertical plane parallel with its end, called a vertical AUXILIARY PLANE, which is perpendicular to the horizontal plane, but at an angle of 60° to the front vertical plane of projection.

From the End Elevation complete the Plan and project all the points down to the Front Elevation, obtaining their heights from the End Elevation.

At any convenient distance to the right, draw a vertical line $a'b'$ for the trace of the central vertical plane ab on the side vertical plane. Draw projecting lines from the Front Elevation across $a'b'$ and on them lay off from $a'b'$ the distances of the points from ab in the Plan. Connect the proper points by lines to complete the Side Elevation.

Close attention should be paid to this figure, as it is the first introduction to the method employed in practice. Note that the line ab is the Plan of a vertical plane and that $a'b'$ is the Side Elevation of the same vertical plane, and that if any point is at a certain distance from ab in the Plan it will be at the same distance from $a'b'$ in the Side Elevation. Note that ef is the trace of a vertical plane at right angles with ab, and that cd is the trace of still another vertical plane at an angle of 30° with ab.

FIG. 48. *To draw a Hexagonal Prism $2\frac{1}{2}$ in. high and 2 in. across the flats.*

In the Plan draw the traces of two vertical planes at right angles and about their intersection construct the Hexagon. Lay off the height upon the Front Elevation, to which project the points from the Plan. In the Side Elevation draw the trace of a vertical plane, from which lay off the width of the Hexagon taken from the Plan.

FIG. 49. *Draw the same Hexagonal Prism, leaning* 30° *to the right, with one side parallel to the Front Elevation.*

As the prism is parallel to the Front Elevation it will appear there in its true size, hence we must commence with this view. Draw the centre line of the prism at the required angle, 30°, with a perpendicular passing through the centre of the base. On this centre line construct the Hexagon for the End Elevation, being careful to make one of its sides parallel with the front vertical plane according to the conditions given. Project the points from this to the Front Elevation, and from the latter complete the Plan and Side Elevation.

FIG. 50. *Draw a Pentagonal Prism* $2\frac{1}{2}$ *in. long, the inscribed circle of the Pentagon being* 2 *in. diameter, the Prism leaning* 45° *to the left and having one side parallel to the Front Elevation.*

Draw the centre line of the prism in the Front Elevation at the given angle, 45°, on which line construct the Pentagon, and complete the projections as before.

As an exercise, draw a plate containing four different prisms leaning in different directions at different angles.

PLATE 7.

FIG. 51. *Draw a 2-in. Hexagonal Pyramid $2\frac{1}{2}$ in. high, and find the exact shape and size of its inclined sides.*

Draw the plan and elevations as before.

To find the shape and size of the inclined sides we can select either of them, because they are alike. We cannot project any of them from the Plan nor from the Front Elevation because they are inclined to both these planes of projection. In the Side Elevation, however, two of them are perpendicular to the plane of projection and we can select the side *ab*. We know that the point *a* is the projection of the apex, and the point *b* that of the base of this side. We also know that if we project the side *ab* upon a plane parallel to it and then revolve this plane into the plane of the paper we will obtain the real shape and size of this side.

To do this, draw a line *cd*, parallel to *ab*, and at any convenient distance from it. Draw projecting lines, perpendicular to *ab*, from the apex *a* to *cd* and from the base *b* across *cd*. On the latter projecting line lay off on each side of the centre line, *cd*, half the length of the base, obtained from the Plan. Connect these points with the projected apex to obtain the true size and shape of the side.

FIG. 52. *Draw the same Pyramid truncated, or cut off, at a point on its axis $1\frac{1}{2}$ in. above the base and find the true shape and size of the surface left by the cut.*

Draw the plan and elevations of the entire pyramid as before and on the Front Elevation lay off a point on the axis $1\frac{1}{2}$ in. above the base, and through this point draw a line at 45° with the axis. Project the points where this line cuts the lines of intersection of the sides of the pyramid to the corresponding lines in the Plan and Side Elevation and complete these views of the truncated pyramid.

To obtain the true shape and size of the cut surface, project it upon an auxiliary plane parallel to it, as in Fig. 51. This would fulfill the conditions given, but it is generally desirable to project the entire object on this auxiliary plane and not merely the surface whose true size is required. This makes a complete drawing of the truncated pyramid, the auxiliary view showing the cut surface in its true size and also in its relation to the rest of the pyramid.

No difficulty need be experienced in drawing these projections as long as the fact is remembered that the centre line in the Plan, in the Side Elevation and in the Auxiliary View are all traces of one and the same vertical plane upon the planes of projections of these views and that any point in either of these views is at the same vertical distance from the centre line as in the others.

FIG. 53. *Draw the same Pyramid with two sides of its base perpendicular*

to the Front Elevation and truncate it by a plane at an angle of 60° *with the base and intersecting the axis* $1\frac{1}{4}$ *in. above the base and draw an auxiliary view parallel with the cut surface.*

FIG. 54. *Draw a Pyramid the same as in Fig.* 51, *and truncate it by a plane parallel to and at a distance of* 1 *in. from the base.*

PLATE 8.

FIG. 55. *Draw a Pentagonal Pyramid* $2\frac{1}{2}$ *in. high, the inscribed circle of the base being* 2 *in. diameter and one side of the base being parallel with the Front Elevation.*

FIG. 56. *To find the length of a line which is inclined to all the planes of projection.*

Take for example the line formed by the intersection of two of the inclined sides of the Pentagonal Prism in Fig. 55, the one of which the Plan is ab, the Front Elevation $a'b'$, and the Side Elevation $a''b''$. Copy these projections exactly. It is now necessary to project ab upon an auxiliary plane parallel to it. Draw through b′ and b″ a horizontal line for the trace of a horizontal plane containing the point b, and draw parallel with ab a line for the trace of this same horizontal plane upon the auxiliary plane of projection, from which line lay off the perpendicular height of the point, a''', above the horizontal plane, obtained from either the Front or

Side Elevation. Project b to b''', and $a'''b'''$ will be the line in its true length.

FIG. 57. *Draw a Triangular Pyramid* $2\frac{1}{2}$ *in. high with each side of its base* $2\frac{1}{2}$ *in. long, and one side making an angle of* 15° *with the front vertical plane, and draw one of the inclined sides in its true size and shape.*

After drawing the projections of the Pyramid project from the Plan the side abc upon a plane perpendicular to this side. The projection will be the line $a'''b'''$, the dotted line passing through b''' being the trace of the horizontal plane of the base on the vertical auxiliary plane of projection, and the point a''' being at the same vertical distance from this line as the vertical height of the Pyramid. Parallel with $a'''b'''$ draw a centre line and project a''' upon it, as a'''', and from b''' project a line across it upon which lay off $b''''c''''$ equal to bc, then $a''''b''''c''''$ will be the true shape and size of the side abc.

FIG. 58. *Copy the three views of the front side of the Pyramid in Fig.* 57, *and from them find the true size and shape of this side.*

The INTERMEDIATE COURSE, which follows this, will treat of solids with curved surfaces, the intersections of solids and the development of their surfaces.

PLATE 1.

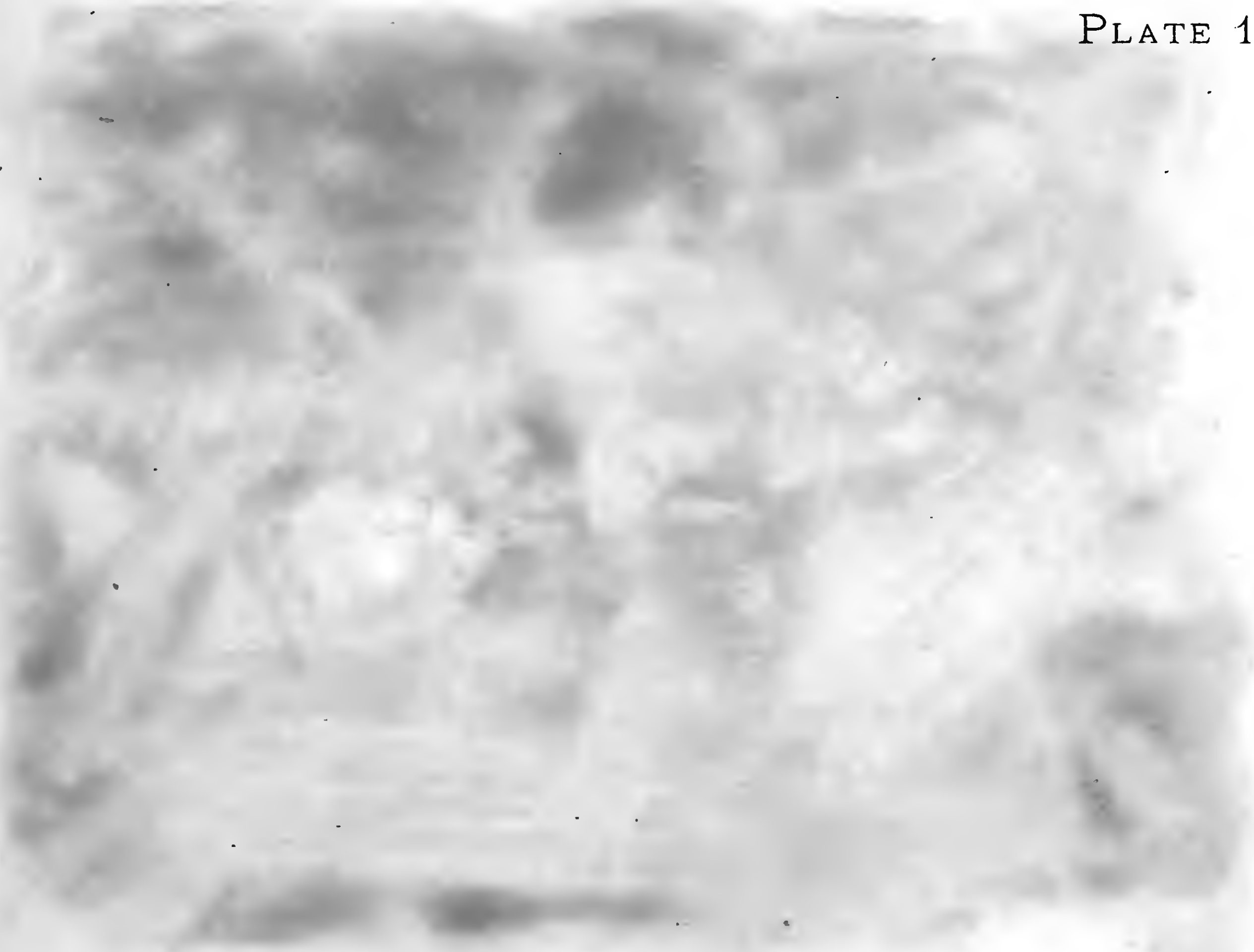

Plate I.

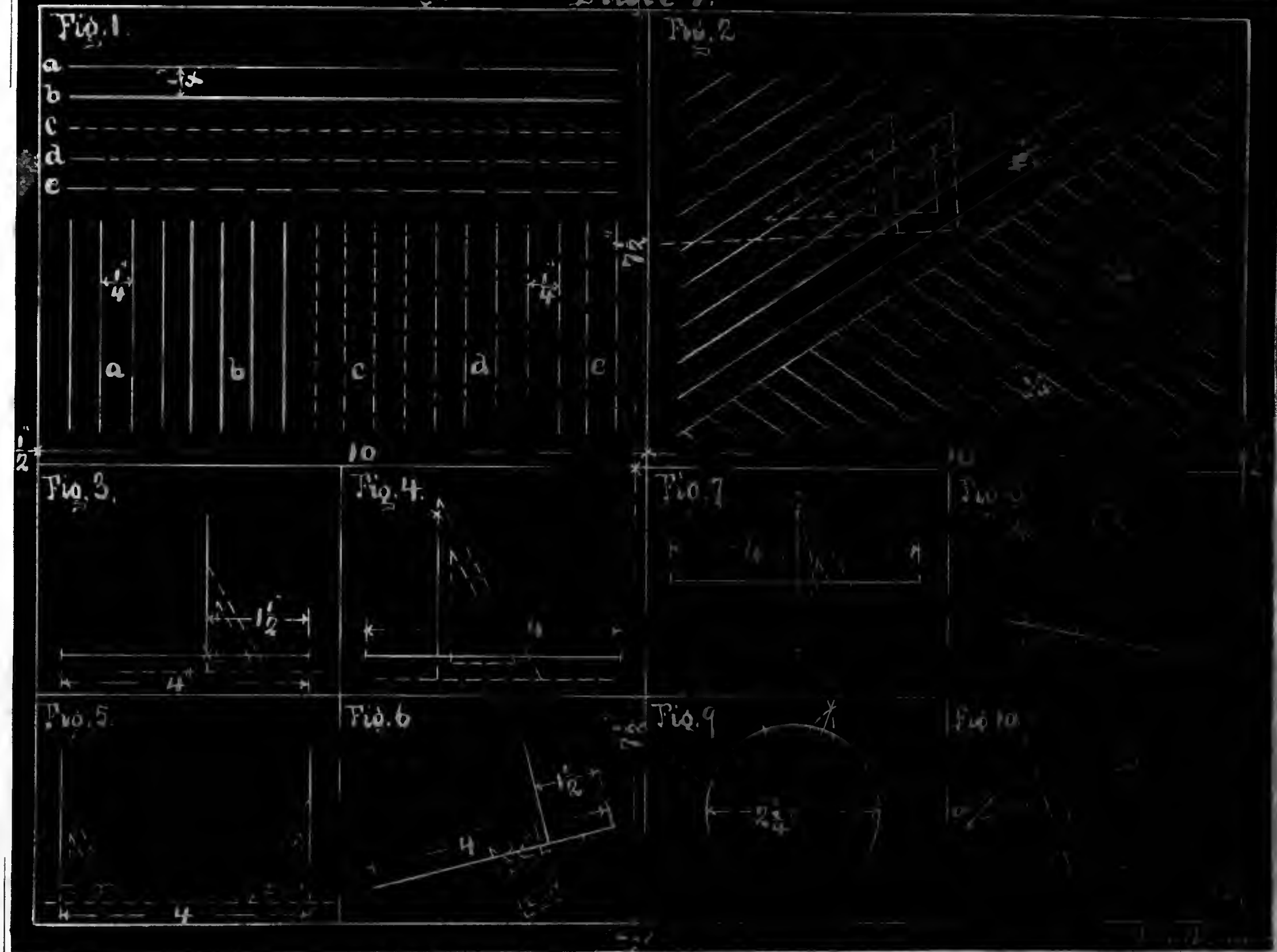

PLATE 2.

Plate 2.

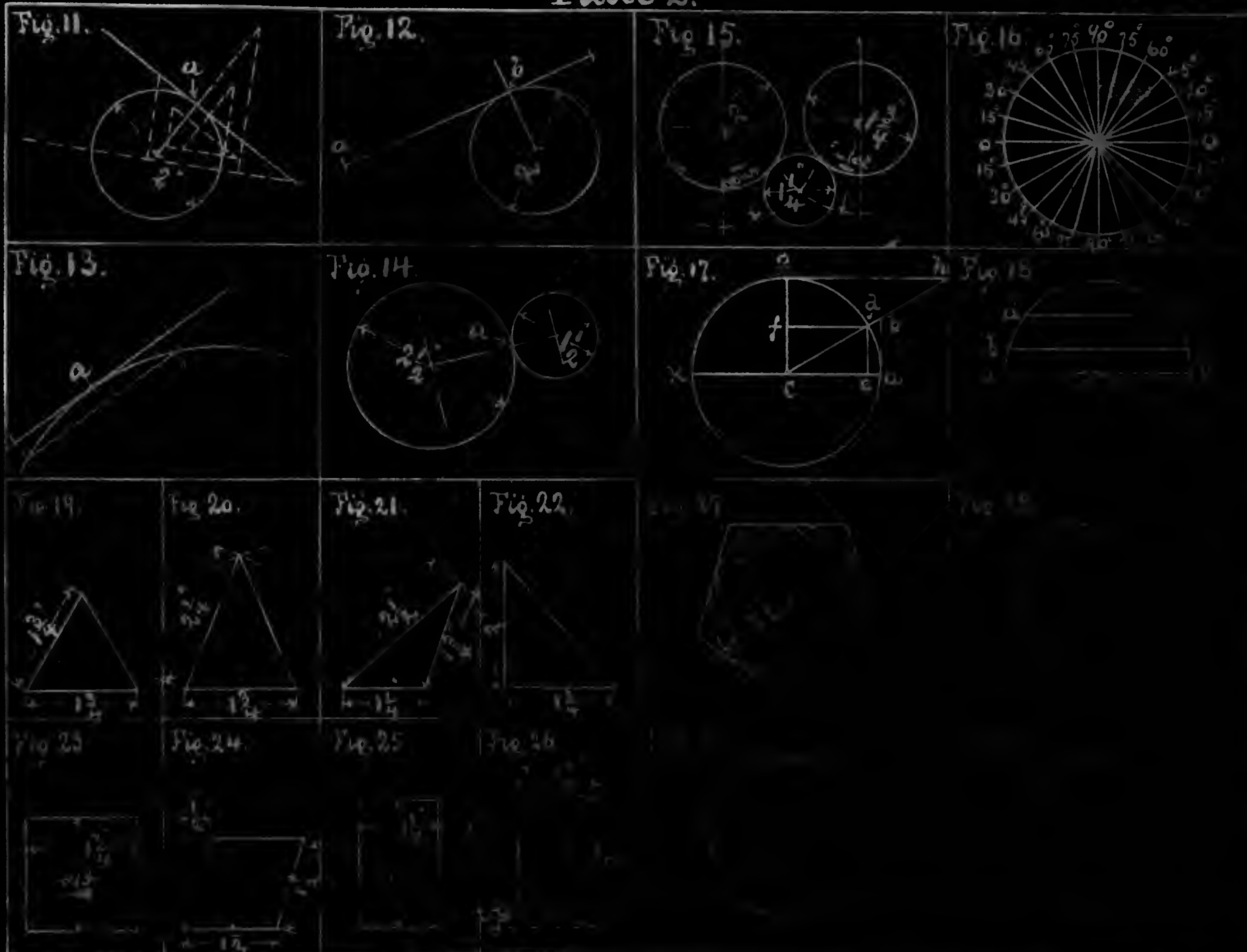
Fig. 11.
Fig. 12.
Fig. 15.
Fig. 16.
Fig. 13.
Fig. 14.
Fig. 17.
Fig. 18
Fig. 19.
Fig. 20.
Fig. 21.
Fig. 22.
Fig. 23
Fig. 24.
Fig. 25
Fig. 26

PLATE 3.

Plate 3.

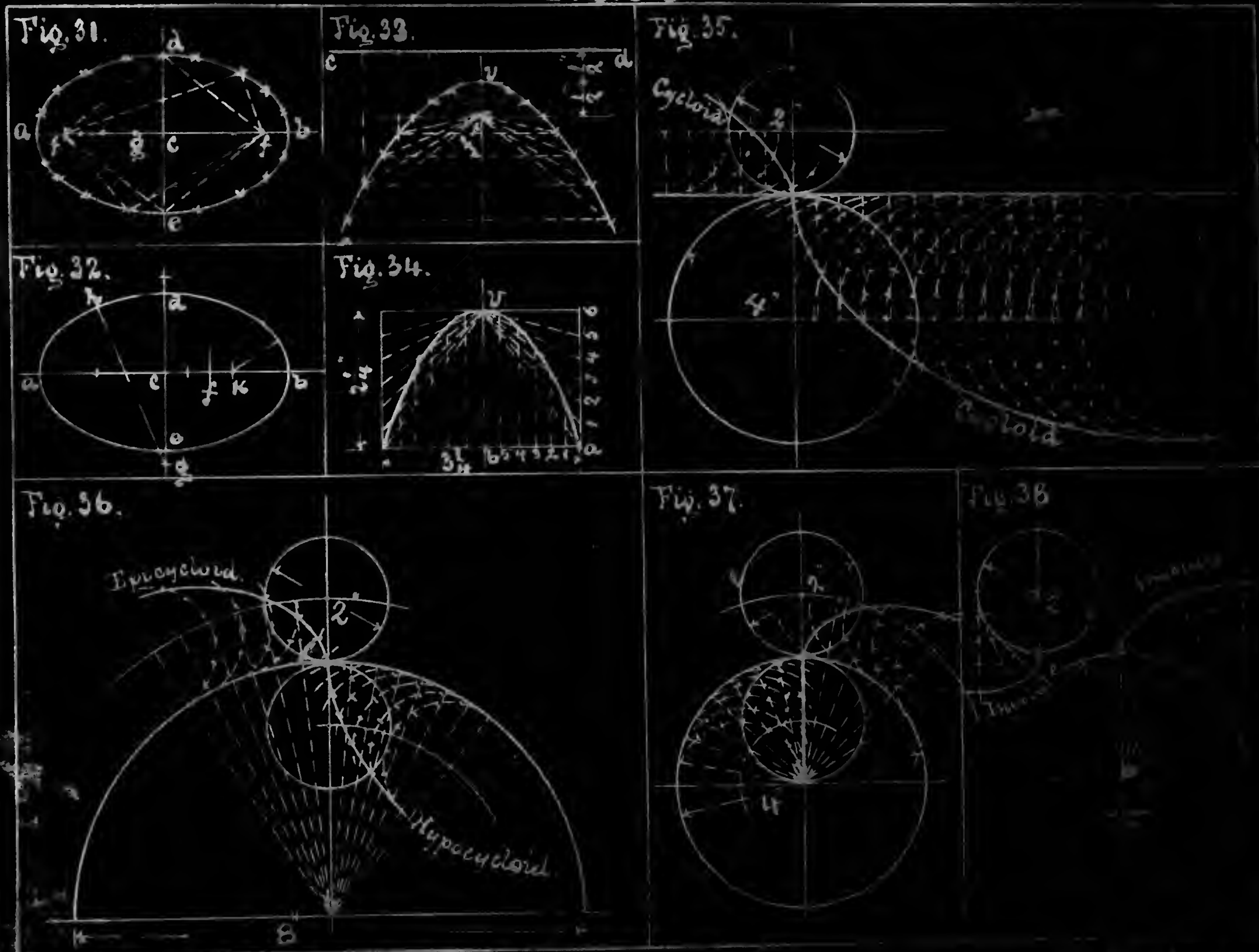

Fig. 31.
Fig. 33.
Fig. 35.
Cycloid
Cycloid
Fig. 32.
Fig. 34.
Fig. 36.
Epicycloid.
Hypocycloid.
Fig. 37.
Fig. 38

PLATE 4.

Plate 3.

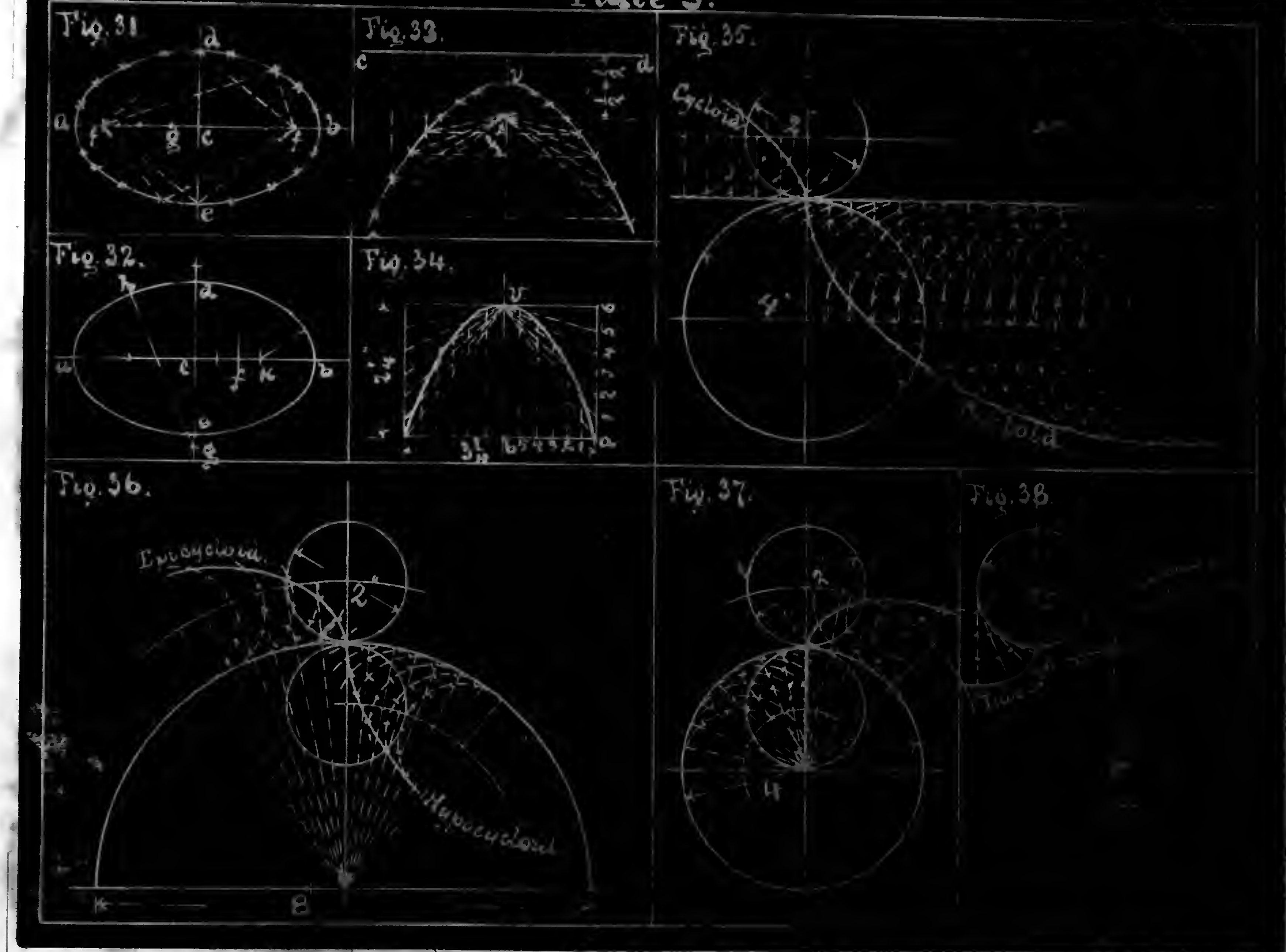
Fig. 31
Fig. 33.
Fig. 35.
Cycloid
Fig. 32.
Fig. 34.
Fig. 36.
Epicycloid
Hypocycloid
Fig. 37.
Fig. 38.

PLATE 5.

PLATE 5.

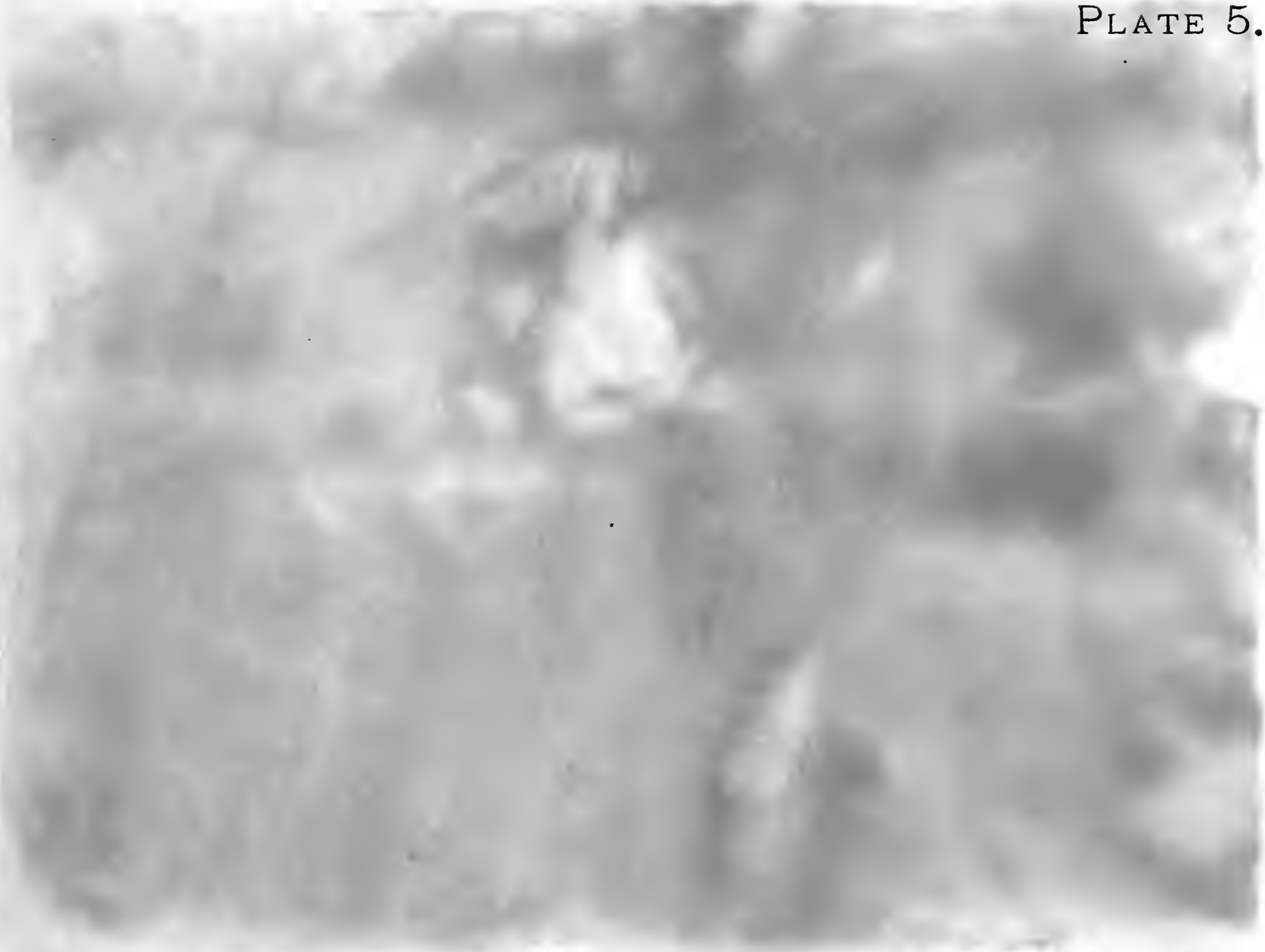

Plate 4.

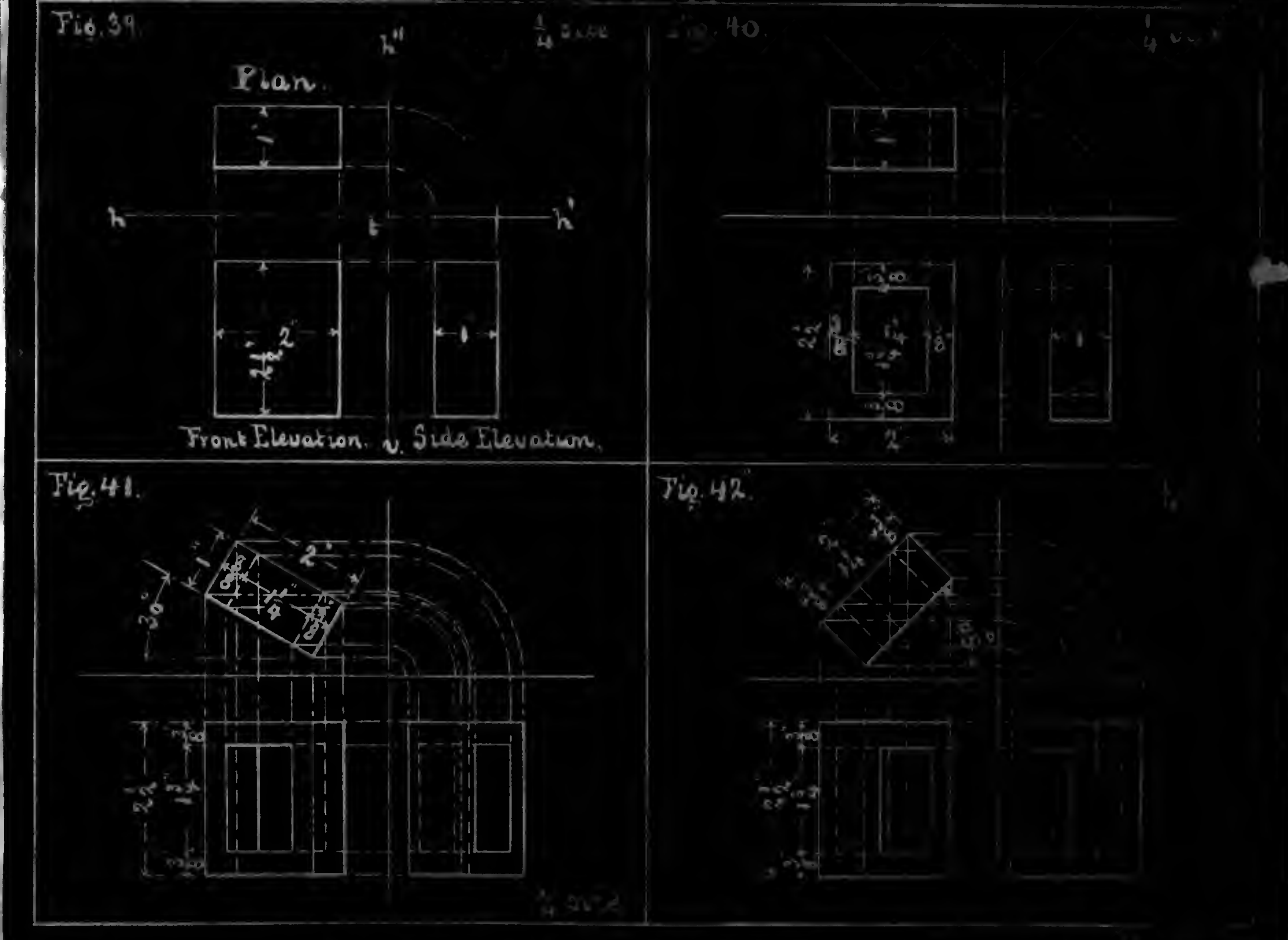

Fig. 39.
Plan.
Front Elevation.
Side Elevation.
Fig. 40.
Fig. 41.
Fig. 42.

PLATE 6.

Plate 5.

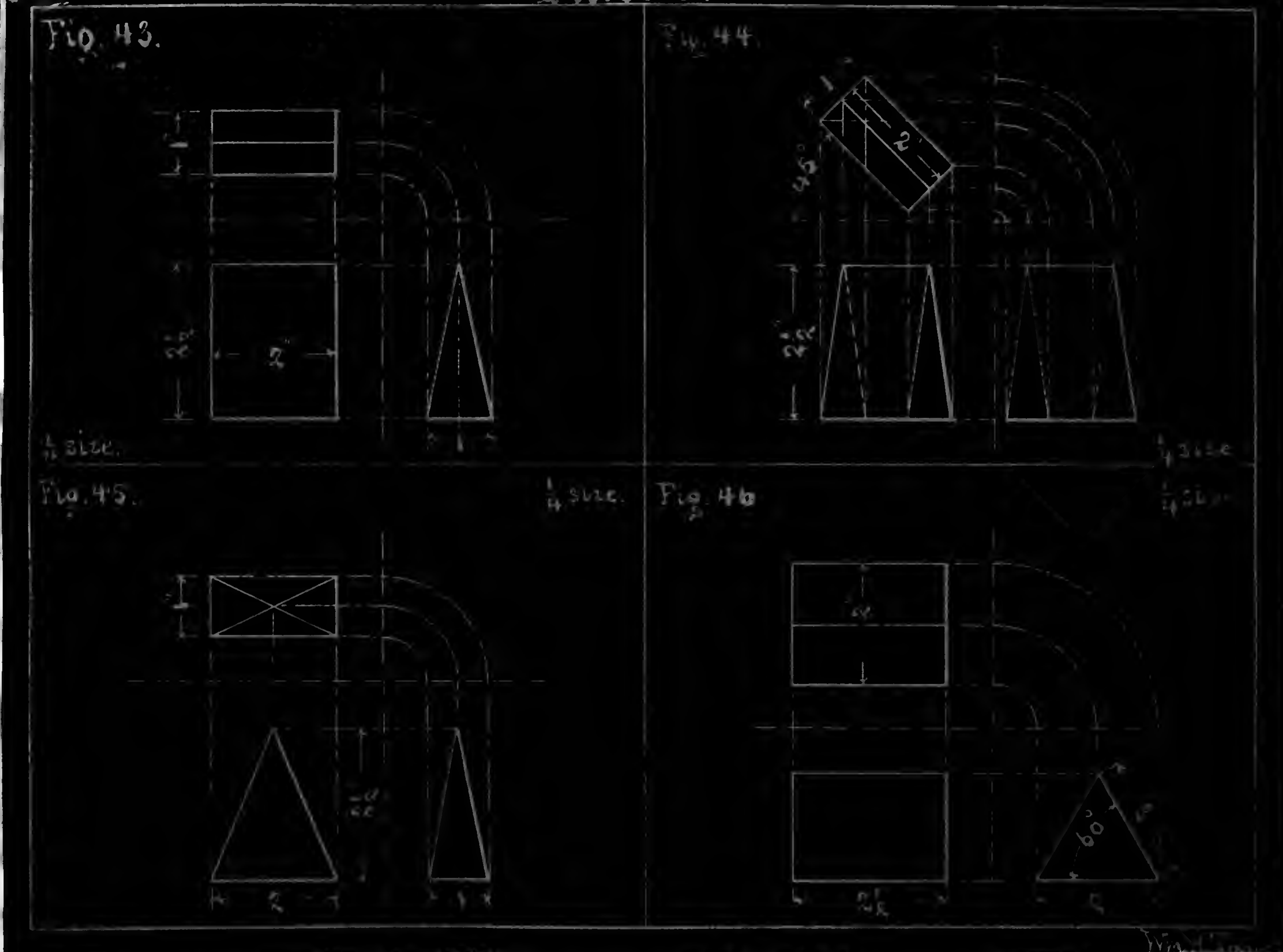

PLATE 7.

Plate 6.

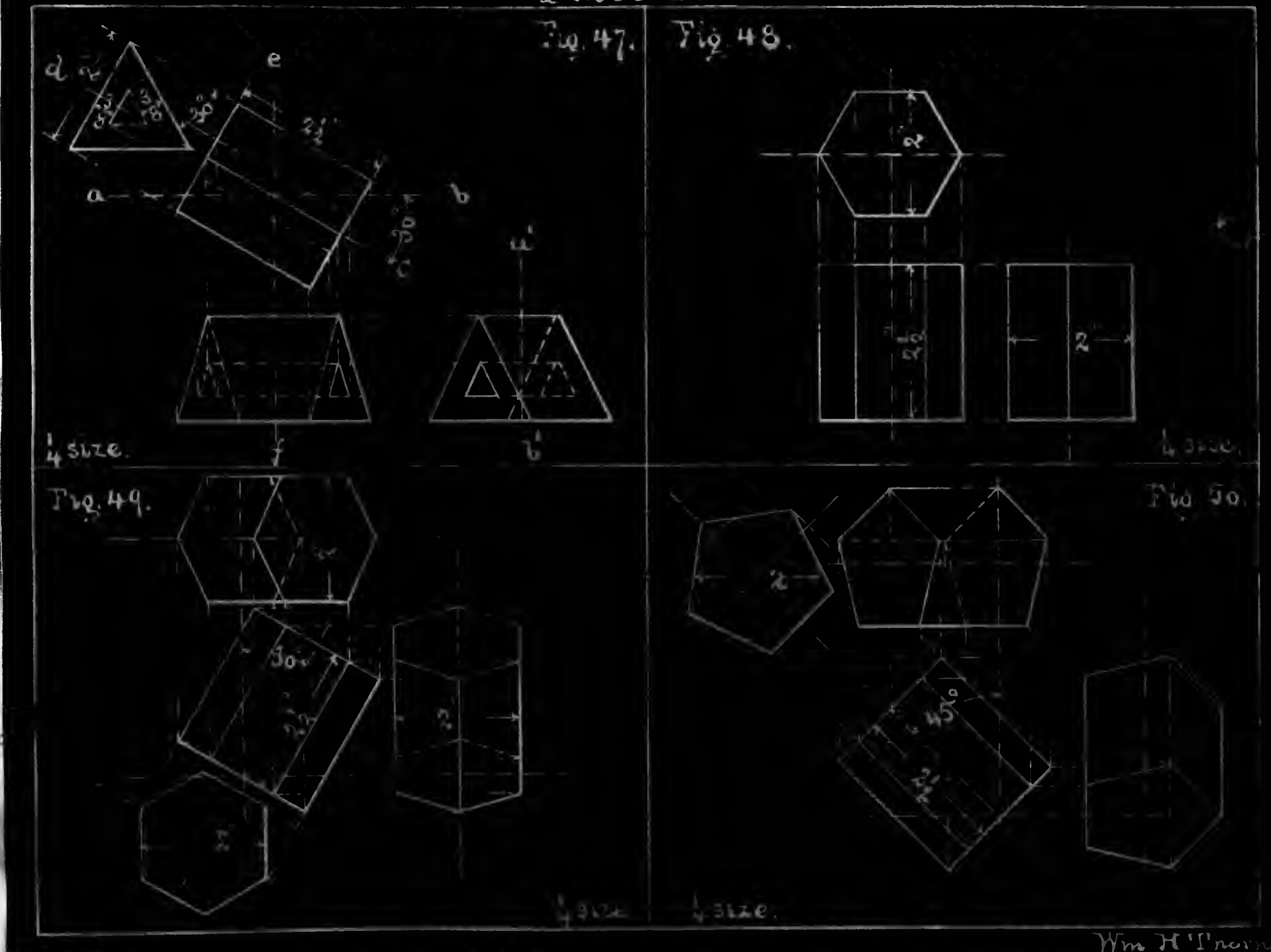
Fig. 47.
Fig. 48.
Fig. 49.
Fig. 50.
d
e
a
b
30°
1/4 size.
2
1/4 size.
30°
45°
1/4 size.
1/4 size.
Wm H Thorne

Plate 8.

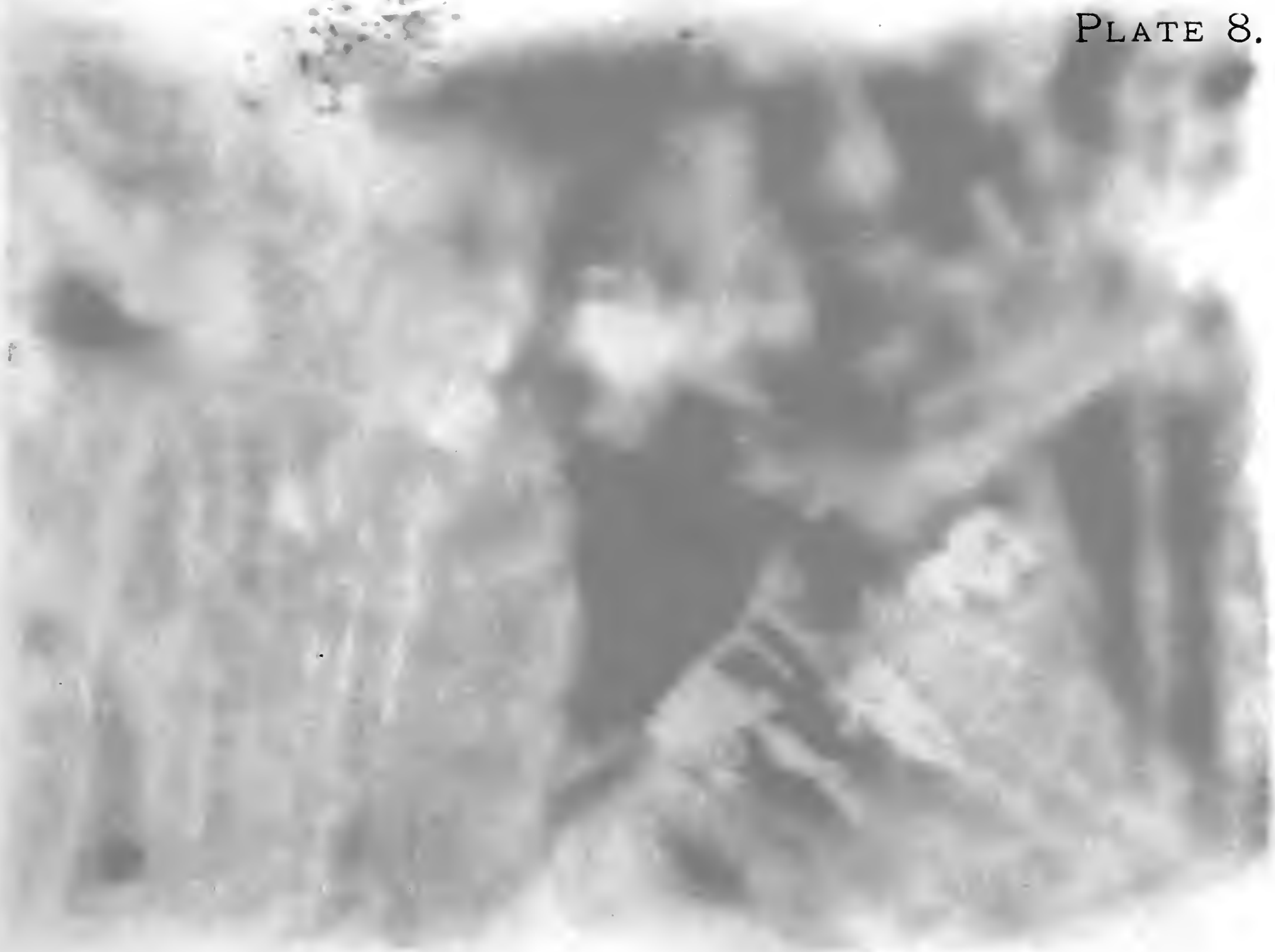

Plate 7.